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Regulatory Impact Analysis of the National Ambient Air Quality Standards for Carbon Monoxide. Final Report

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This report examines the cost, changes in exposures seen by the public, and economic impacts associated with setting alternative carbon monoxide NAAQS. Four alternative 8-hour NAAQS were analyzed: 9 ppm, one observed exceedance, and 9, 12, and 15 ppm one expected exceedance of daily maxima. Three time periods of analyses are used: 1987, 1990, and 1995.

Also discussed is the health evidence supporting the carbon monoxide (CO) standard and the reduction in exposures associated with different CO standards.

The report is intended to fulfill the requirements of E.O. 12291, which requires that a regulatory analysis be undertaken for every rule resulting in an annual impact of $100 million or more.

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Strategies and Air Standards Division
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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This final regulatory impact analysis (RIA) was reviewed within the U.S. Environmental Protection Agency (EPA) and by the Office of Management and Budget (OMB) and is being published in conjunction with publication of EPA's final decision on the carbon monoxide national ambient air quality standards.

This RIA was prepared by the Strategies and Air Standards Division of the Office of Air Quality Planning and Standards (OAQPS). The principal authors include: Thomas McCurdy, Harvey Richmond, and Dave McLamb. Questions regarding this report should be addressed to Thomas McCurdy at MD-12, U.S. EPA, Research Triangle Park, N.C. 27711; (919) 541-5655 (FTS 629-5655).

This report has been reviewed by OAQPS, U.S. EPA and approved for publication. Menion of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

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I. INTRODUCTION

This final Regulatory Impact Analysis (RIA) of the carbon monoxide (CO) national ambient air quality standards (NAAQS) has been prepared in accordance with Executive Order 12291, which requires that an RIA be done for every "major rule." As discussed below, the Environmental Protection Agency (EPA) has decided to retain the current primary NAAQS for CO and to revoke the existing secondary NAAQS for CO. Because full compliance with the current primary standards could result in an annual impact of $100 million or more on the economy, EPA has determined that this retention is a major action.

As provided for in sections 108 and 109 of the Clean Air Act as amended, EPA has reviewed and revised the criteria upon which the existing primary (to protect public health) and secondary (to protect public welfare) standards are based to determine if revisions are appropriate. The existing primary and secondary standards for CO are both currently set at 10 mg/m^3 (9 ppm), 8-hour average and 40 mg/m^3 (35 ppm), 1-hour average neither to be exceeded more than once per year. On August 18, 1980, EPA proposed certain changes in the standards based on the scientific knowledge reported in the revised criteria document for CO (45 FR 55066). Based on developments subsequent to proposal and the Agency's review of public comments, EPA's final decision, announced separately in the Federal Register, is to retain the existing primary standards at this time and to revoke the secondary (welfare) NAAQS for CO. Since there are no welfare effects associated with exposure to CO levels at or near ambient levels, this RIA focuses on the review of the primary standards.

The Clean Air Act specifically requires that primary and secondary NAAQS be based on scientific criteria relating to the level that should

be attained to protect public health and welfare adequately. The courts have endorsed a reading of the Act that excludes reliance on the cost or feasibility of achieving such standards in determining the level of the primary standards. Accordingly, EPA has not considered the results of this RIA in selecting the proposed standards or in its final decision to retain the primary standards and revoke the existing secondary standards.

This RIA examines the benefits, costs, and other economic impacts of alternative primary CO standards on both the public and private sectors. In specifying the alternatives to be analyzed, EPA took account of the legislative requirements affecting the development and revision of primary and secondary NAAQS and relied heavily on the document Review of the NAAQS for Carbon Monoxide: Reassessment of Scientific and Technical Information (Staff Reassessment, EPA, 1984a). The Staff Reassessment interprets the most relevant scientific and technical informations reviewed in the revised Air Quality Criteria for Carbon Monoxide (Criteria Document, EPA, 1979b) and the Revised Evaluation of Health Effects Associated with Carbon Monoxide Exposure: An Addendum to the 1979 Air Quality Criteria Document for Carbon Monoxide (Addendum, EPA, 1984b). The Staff Reassessment, which has undergone careful review by the Clean Air Scientific Advisory Committee (an independent advisory group), serves to identify those conclusions and uncertainties in the available scientific literature that should be considered in determining the form, and level for both the primary and secondary standards.

II. STATEMENT OF NEEDS AND CONSEQUENCES

This chapter of the RIA summarizes the statutory requirements affecting the development and revision of NAAQS and briefly describes the nature of the ambient carbon monoxide (CO) problem. The need for regulatory action and the consequences of the regulation in terms of improving the functioning of the market are also discussed.

A. Legislative Requirements Affecting Development and Revision of NAAQS

Two sections of the Clean Air Act govern the establishment and revision of national ambient air quality standards (NAAQS). First, as a preliminary step in developing standards, section 108 (42 U.S.C. § 7408) directs the Administrator to identify all pollutants which may reasonably be anticipated to endanger public health or welfare and to issue air quality criteria for such pollutants. Such air quality criteria are to reflect the latest scientific information useful in indicating the kind and extent of all identifiable effects on public health or welfare that may be expected from the presence of the pollutant in the ambient air.

Section 109(d) of the Act (42 U.S.C. § 7409(d)) requires periodic review and, if appropriate, revision of existing criteria and standards. If, in the Administrator's judgment, the Agency's review and revision of criteria make appropriate the proposal of new or revised standards, such standards are to be revised and promulgated in accordance with section 109(b). Alternatively, the Administrator may find that revision of the standard is not appropriate and conclude the review by retaining the existing standard. Section 109(b)(1) defines the primary standard as that ambient air quality standard the attainment and maintenance of which in the judgment of the Administrator, based on the criteria and allowing adequate margin of safety, is requisite to protect the public health. The secondary standard, as

defined in section 109(b)(2), must specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on the criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. Welfare effects are defined in section 302(h) (42 U.S.C. § 7602(b)) and include effects on soils, water, crops, vegetation, man-made materials, animals, weather, visibility, hazards to transportation, economic values, personal comfort and well-being, and similar factors.

The Act, its legislative history, and recent judicial decisions (Lead Industries Association, Inc. v. EPA, 1980; American Petroleum Institute v. EPA, 1981) appear to preclude reliance on the costs and technological feasibility of attainment in setting primary NAAQS. Such factors can be considered to a limited degree in the development of state plans to implement such standards. Under section 110 of the Act, the States are to submit to EPA for approval State Implementation Plans (SIPs) that provide for the attainment and maintenance of NAAQS by certain deadlines.

Finally, section 109(d) of the Act directs the Administrator to review all existing criteria and NAAQS at 5-year intervals. When warranted by such review, the Administrator is to revise NAAQS.

B. Nature of the Carbon Monoxide Problem

Carbon monoxide is a colorless, odorless gas that is toxic to mammals because of its strong tendency to combine with hemoglobin to form carboxyhemoglobin (COHb). Thus, the oxygen-carrying capacity of the blood is reduced since hemoglobin that has combined with CO in this manner is not available to transport oxygen. The resultant hypoxemia (deficient oxygenation of the blood) can have detrimental effects on the cardiovascular, central nervous, pulmonary, and other body systems. Low-level CO exposures (producing

group mean COHb levels in the range of 2.9 to 4.5 percent) have been shown to cause aggravation of cardiovascular disease. This aggravation consists of decreased time to onset of pain and increased duration of pain in persons with angina (Anderson et al., 1973). The Clean Air Scientific Advisory Committee (CASAC) CO Subcommittee has concluded following a review of the peer-reviewed scientific literature (not including the Aronow studies) that the critical effects level for NAAQS-setting purposes is approximately 3 percent COHb (not including a margin of safety) (Lippmann, 1984).

Carbon monoxide is a normal constituent of the plant environment. Plants can both metabolize and produce CO. This fact may explain the relatively high levels of CO necessary to damage vegetation. The lowest level for which significant effects in vegetation has been reported is 100 ppm for 3 to 34 days (EPA, 1979b). The effect observed in this study was an inhibition of nitrogen fixation in legumes. Since CO concentrations of this magnitude and duration are not observed in the ambient air, it is very unlikely that any damage to vegetation will occur from CO air pollution. No other effects on welfare have been associated with CO exposures at or near ambient levels. Because no standard appears to be needed to protect the public welfare from any known or anticipated adverse effects from ambient CO exposures, EPA is revoking the existing secondary standard. Consequently this RIA focuses on the primary standards only.

Carbon monoxide air pollution is a problem affecting most urban areas in the United States. In 1983, man-made sources accounted for about 67.6 million metric tons of CO emissions in the United States. About 71% of the total CO emissions were from mobile sources and most high CO monitor readings occurred in areas with heavy traffic concentration. Thus, control strategies for attaining the CO NAAQS have focused primarily on reducing

emissions from motor vehicles. Additional information concerning sources of CO emissions is contained in the Cost and Economic Assessment of Alternative National Ambient Air Quality Standards for Carbon Monoxide (EPA, 1985).

The primary control strategy for CO emissions has been the implementation and enforcement of increasingly stringent CO exhaust emission standards in accordance with the federal motor vehicle control program (FMVCP) provisions of the Clean Air Act Amendments of 1977. For example, the CO emission standard for non-California, light duty vehicles is 3.4 grams per mile (gpm) for model years 1981 and beyond. This is approximately a 90% reduction in emissions when compared to light duty vehicles manufactured prior to 1970. Two other basic control strategies exist for reducing mobile source emissions of CO including inspection and maintenance (I&M) programs for light-duty vehicles and transportation control measures (TCM) which reduce emissions by reducing travel and improving traffic flow. Additional information describing the FMVCP, I&M, and TCM programs and their costs and effectiveness are contained in the Cost and Economic Assessment (EPA, 1985) and in the Control Techniques Document (EPA, 1979c). The cost and effectiveness of control techniques for stationary sources are also discussed in these documents.

C. Need for Regulatory Action

In the absence of government regulation, market systems have failed to deal effectively with air pollution, because airsheds have been treated as public goods and because most air polluters do not internalize the full damage caused by their emissions. For an individual firm, pollution is usually an unusable by-product which can be disposed of at no cost by venting it to the atmosphere. However, in the atmosphere,

pollution causes real costs to be incurred by others. This is generally referred to as a negative externality in economic theory.

The fact that the producer, or consumer, whose activity results in air pollution, does not bear the full costs of his action leads to a divergence between private costs and social costs. This is referred to as "market failure" because it causes a misallocation of society's resources, with more resources being devoted to the polluting activity than would be if the polluter had to bear the full cost.

There are a variety of market and nonmarket mechanisms available to correct this situation. Some of the principal market mechanisms are briefly described in Chapter III of this RIA ("Alternatives Examined"). Other than regulation, nonmarket approaches would include negotiations or litigation under tort law and general common law. In theory, these latter approaches might result in payments to individuals to compensate them for the damages they incur.

Such resolutions might not occur, however, in the absence of government intervention. Two major impediments block the correction of pollution inefficiencies and inequities by the private market. The first is high transaction costs when millions of individuals are affected by thousands of polluters. The transaction costs of compensating individuals adversely impacted by air pollution include contacting the individuals affected, apportioning injury to each from each pollution source, and executing the appropriate damage suits or negotiations. If left to the private market, each polluter and each affected individual would have to litigate or negotiate on their own or organize into groups for these purposes. The transaction costs involved would be so high as probably to exceed the benefits of the pollution reduction.

The second factor discouraging private sector resolution of the CO pollution problem is that pollution abatement tends to be a public good. That is, after CO pollution has been abated, benefits of the abatement can be enjoyed by additional people at no additional cost. This constitutes the classic "free rider" problem. Any particular individual is reluctant to contribute time or money to reduce CO emissions knowing that his actions will have little impact on how clean the air he breathes actually is.

In view of the clear legal requirements placed on EPA by the Clean Air Act, the Agency is planning to retain the primary NAAQS for CO to provide adequate protection of public health. As this regulatory analysis shows, there are resource costs associated with this governmental intervention (see Chapter V, "Cost Analysis"). However, in view of the scientific data on CO health effects this action is required by the Clean Air Act. In addition, EPA believes that the cost of this abatement through government action is less expensive than with any reasonably available private sector alternatives. Finally, these standards will mitigate the negative externalities which would otherwise occur due to the failure of the marketplace.

III. ALTERNATIVES EXAMINED

This chapter briefly presents potential alternatives to the 1980 proposed revisions of NAAQS for CO. The outline for the chapter is adopted from Executive Order 12291 which requires that at a minimum the following alternatives be examined:

a) No regulation

b) Regulations beyond the scope of present legislation

c) Market oriented alternatives

d) Alternative stringency levels and implementation schedules.

Although Executive Order 12291 requires that all alternatives be examined, only the most promising ones need be analyzed in detail.

A. No Regulation

Abandoning current regulatory requirements for CO would result in a reliance on private efforts to reduce emissions and on the absorptive capacity of the atmosphere. The most likely avenues for private efforts would be either negotiation or litigation under tort and general common law. Generally speaking there is no incentive for a single company to enter into negotiations with individuals to reduce CO emissions. For an individual firm, the cost of reducing emissions would leave that firm at a competitive disadvantage. Litigation by those damaged could be pursued either to obtain a reduction in emissions or to obtain payment for damages incurred (or both). The costs of such litigation would likely be very high since the individual or classes of individuals bringing suit would have to prove damages. Moreover, there is little incentive for all those affected by air pollution to join together in such a suit since everyone would enjoy the benefits of a successful suit to reduce emissions regardless of the extent of their participation.

Because the Clean Air Act requires the Administrator to prescribe standards for pollutants, such as CO, which have adverse effects on public health or welfare and because of the impracticality of private efforts, the option of no regulation has not been analyzed in any further detail.

B. Other Regulatory Approaches

Other regulatory approaches include such options as performance and technology standards and regional or State air quality standards. Performance and technology standards are required by the present law in a variety of forms (e.g., new source performance standards (NSPS) for new and modified sources, motor vehicle standards, lowest achievable emission rate (LAER) and reasonably available control technology (RACT) in non-attainment areas, etc.). They are not based solely on health and welfare criteria but are designed, in part, to augment control strategies for attainment of the air quality standards. These standards generally specify allowable emission rates for specific source categories. The LAER and RACT requirements are intended to allow growth in non-attainment areas while promoting progress towards eventual attainment. NSPS and motor vehicle standards help to reduce the likelihood of future pollution problems by controlling new sources. EPA is required to consider technology and cost in setting NSPS and RACT requirements.

Performance and technology based standards serve as useful adjuncts to ambient standards. However, they cannot serve as substitutes for ambient standards since even perfect compliance with them may not produce acceptable air quality levels. Despite the application of such standards, local meteorology, the interaction of multiple sources, and the level of the standard itself (the standards are set on the basis of technology and cost) could produce air quality levels that do not protect public health and welfare.

Regional or State differences in terrain and meteorology as well as valuations of clean air have been cited as reasons for adopting regional or State air quality standards. Variations in terrain and meteorology are considered in setting SIP emission limits to achieve a NAAQS. Such variations do not generally change the effect of particular levels of pollution on public health and welfare. Moreover, transport of pollutants across boundaries would make a system of regional or State air quality standards difficult to enforce. The Clean Air Act requires national not regional standards.

In summary, the regulatory alternatives outlined above have not been analyzed in detail in this RIA because of the Clean Air Act requirements for setting and revising NAAQS. However, the performance and technology based standards are helpful in augmenting control strategies for meeting ambient standards.

C. Market-Oriented Alternatives

There are several market-oriented approaches which can be considered as means for achieving the NAAQS for CO, but not as a substitute for NAAQS These approaches include pollution charges, marketable permits, and subsidies and are briefly discussed below.

Charges. This policy would involve a charge (or tax) being set on each unit of a pollutant emitted. Firms would then choose the amount of abatement that minimizes their total cost, including the pollution charge. Pollution is abated until the marginal cost of abatement is equal to the pollution charge. The regulatory agency would have to set the level of the charge or charges in a manner that would result in the desired air quality. This could be quite difficult and might require continued adjustments to account for inflation and growth.

Permits. A permit system would allow a pollution source to purchase a permit in order to emit a specified amount of a pollutant over a specified period of time at a specified location. A fixed number of permits could be issued and auctioned off to the highest bidders. Alternatively, the permits can be distributed among the sources, who could then trade these permits as they see fit. If the number of permits and emission allowances are correctly fixed in advance, then the desired ambient standard would be achieved. Again, this may be difficult in areas with numerous and diverse sources.

Subsidies. A subsidy system pays sources for each unit of pollution that they do not emit. This can take the form of direct payments or tax credits. Subsidies and charges are similar in that both increase the opportunity cost of polluting, the former by causing each unit of pollution to entail forgoing the subsidy which could be received if it were not emitted. Thus, the subsidy is similar to a charge, except in two respects:

(a) Administratively, there is the problem of determining the actual abatement of each source. There must be a determination of what its pollution would have been in the absence of the subsidy, and this determination must be adjusted as conditions change. These determinations are difficult and may depend upon information from the polluters, who could have the incentive to strategically misrepresent their intended emissions.

(b) The long-run effects of subsidies may be quite different than for permits or charges, since the former increase profit levels or incomes for polluting industries and the latter decrease them. Thus, in the long-run, subsidies will result

in firms entering the polluting industry, but permits or charges will cause firms to leave it. Consequently, a fixed subsidy rate will yield greater pollution levels than equivalent permits or charges, although each individual firm will behave identically under the two systems. Also subsidies would likely increase dependence on capital intensive solutions.

Summary. Although the Clean Air Act does not contemplate consideration of these market-oriented alternatives in setting the NAAQS, it does not prevent States from using such approaches in attaining air quality standards. Thus, to the extent they are permitted by EPA's regulations for development of SIPs, the States may consider such market-oriented approaches as described above in the implementation of the NAAQS.

D. Regulatory Alternatives within the Scope of Present Legislation

The Clean Air Act requires that primary NAAQS be set at levels which protect the public health, including that of sensitive individuals, with an adequate margin of safety. The secondary NAAQS must be adequate to protect public welfare from any known or anticipated adverse effects.

The assessment of the available quantitative and qualitative health effects data presented in the Criteria Document, Addendum, and Staff Reassessment, together with recommendations of CASAC and other public commenters, suggested several alternatives. For a comprehensive discussion of the scientific data that served as the basis for these alternatives as well as the rationale for the Administrator's approach to this decision, the reader is referred to the Criteria Document, the Addendum Staff Reassessment, and the preamble to the final action.

Since August 18, 1980, when the revised CO standards were proposed, a number of alternative 8-hour standards have been considered. The alternatives being analyzed in this final RIA for the 8-hour primary standard are shown in Table 1. The 1-hour standard is not being addressed in this analysis because all areas expected to attain the various 8-hour standard alternatives are also expected to attain any 1-hour standard under consideration, and the amount of control needed is higher for 8-hour standards than for their equivalent 1-hour standards.

Table 1: Alternative Levels of NAAQS for CO

	Averaging Time (hours)	Level (ppm)	Exceedances Allowed per year
Current Standard	8	9	1 observed
Alternative A	8	9	1 expected
Alternative B	8	12	1 expected
Alternative C	8	15	1 expected

IV. ASSESSING BENEFITS

A. Assessing Benefits of Air Pollution Control

Air pollution has adverse effects on human health and welfare. Controlling pollution means reducing these adverse effects. The benefits of air pollution control are the values (both known and unknown) to society brought about by reduction in adverse health and welfare effects.

A proper economic benefits analysis is based on appropriate economic theories and analytical tools to measure all values to all individuals in dollar or other appropriate units for all expected impacts. The translation of impacts into dollar values, where possible, allows the summation of impacts and direct comparison with the costs of pollution control. Estimating the benefits of air pollution control requires an understanding of how changes in pollution emissions affect atmospheric conditions and thereby affect people's health and welfare, and how these effects are valued. These links are illustrated in Figure 1.

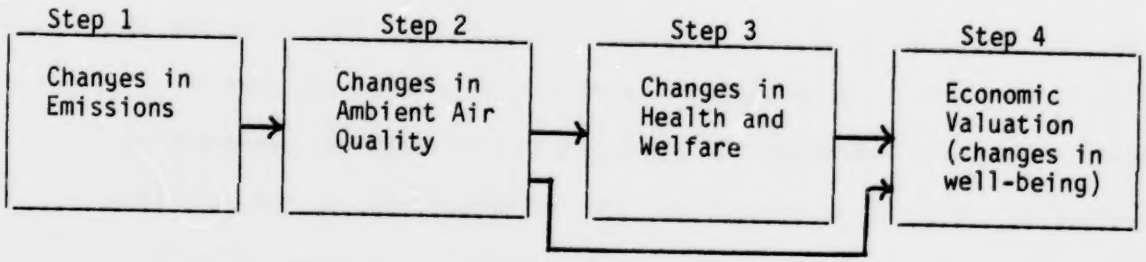

Figure 1

STEPS IN MEASURING BENEFITS

A complete benefits analysis will examine all effects of changes in air pollution in Steps 3 and 4 of Figure 1, or in some cases will go straight from Step 2 to Step 4.

The Clean Air Act is designed to prevent adverse effects, such as:

1. Health

   adverse impacts to human health--acute or chronic effects that result in increased mortality or morbidity.

2. Welfare

   a. adverse impacts to materials--corrosion, soiling and other damage to building materials, metals, fabrics, equipment, etc.

   b. adverse impacts to vegetation--reduction in productivity or aesthetic appeal of domestic crops, ornamental plants and native vegetation.

   c. adverse impacts to animals--effects on health and productivity of livestock, pets, and wildlife.

   d. adverse impacts on climate--changes in temperatures and/or precipitation.

   e. adverse aesthetic impacts--reduced visibility or visual discoloration of the air and objects viewed through it and other aesthetic effects such as unpleasant odors.

It is the effects of these impacts on well-being, including the risks of incurring them and the costs of avoiding or ameliorating them, that determine the economic valuation of the changes in air quality. This valuation can be positive or negative depending on whether air quality improves or deteriorates. For improvements, the valuation is positive, representing benefits of the pollution reduction, and for deterioration, the valuation will represent damages of the additional pollution. In order to avoid confusion, the term costs will be reserved for reference to the costs of pollution control while damages will refer to the adverse effects of pollution.

The appropriate benefit measure of pollution control will reflect the value of the reduction in the need to prevent or ameliorate adverse effects, the value of reduced risks of incurring adverse effects, and the value of

reductions in adverse effects actually incurred. These benefits are often classified into three categories--user, option, and existence values. User values are the benefits of improved air quality that the individual expects to enjoy directly. Option values result from uncertainty concerning future demand for air quality. For example, an individual may wish to know that he will be able to obtain a particular level of air quality in the future due to uncertainty about changes in his susceptibility to the adverse health impacts of air pollution. This may be a particularly important value when changes in air quality are difficult to reverse. People may also want to preserve a particular level of air quality across the country simply to know that it exists, although they never expect to experience it directly in all locations. This is called existence value.

The approach used in benefits estimation is derived from economic welfare theory. The benefits of a change in air quality are said to be equal to the change in well-being, or utility, that results. Such a change in utility is difficult to quantify, but the standard dollar measure is how much of other goods and services the individual is willing to give up in order to obtain or prevent the change. The rational consumer will only be willing to make the exchange if his utility is enhanced or unchanged. The individual's maximum willingness to pay (WTP) in order to obtain a desirable change or prevent an undesirable change is that amount that would keep his utility constant at either the initial utility level or at the utility level that would be obtained if the change were to occur. Dollars are used to represent how much of other things he is giving up.

For market goods, the marginal WTP for an additional unit of a good service is typically represented by the market price of the good or service. WTP for different quantities can therefore be taken from the

market demand curve for the good or service (see Harberger, 1971). For non-market goods, such as air resources, market prices do not exist and other methods must be employed to estimate measures of WTP (see Rowe and Chestnut, 1981, for a review). WTP for air pollution control will depend on income, tastes and preferences, and the prices of alternatives and other goods. For example, if all the effects of air pollution could be ameliorated with air conditioning, an individual may not be willing to pay more for air pollution control than it would cost him for air conditioning. Since the individual will not be sure whether he will actually incur the potential effects of air pollution, he may also be willing to pay an additional amount in order to reduce the risk of suffering undesirable impacts.

A slightly different measure than WTP for the benefits of a change in air pollution is the willingness to accept compensation (WTA) in return for incurring an increase in air pollution or foregoing a decrease in air pollution. The difference between WTA and WTP is whether the point of reference is the more preferred or less preferred level of air quality. The WTP measure presumes that an individual does not have a predetermined right to any particular level of air quality, in which case the point of reference is the lower level of air quality. The WTA measure presumes that the appropriate point of reference is the improved level of air quality. The Clean Air Act states that the public has a right to be protected from adverse health effects of air pollution. It might be argued, therefore, that the appropriate benefit measure is the amount the consumer is willing to accept in compensation for incurring adverse health effects or foregoing reductions in adverse health effects.

It has been demonstrated theoretically that under typical conditions WTP and WTA measures would not be expected to differ greatly, but several

empirical studies concerning air pollution control benefits have found significant differences between the two, with empirical WTA measures exceeding WTP measures (see Rowe and Chestnut, 1981).

Changes in air quality will affect many people across many time periods so that a total benefits measure must be some combination of benefits for all affected individuals through all relevant time periods. The standard procedure, which meets the economic efficiency criterion (Harberger, 1971), is to simply sum WTP or WTA for all individuals and discount them through time. This ignores interpersonal differences in income and other factors. Distribution impacts of a change in air quality across different regions, people, and time periods may be of concern and can be considered separately (see Rowe and Chestnut, 1981a).

B. Estimating Benefits Associated with Alternative CO NAAQS

To perform a comprehensive benefits analysis for CO that is fully consistent with economic welfare theory and available scientific evidence would require a number of complex research tasks that have not yet been undertaken for CO. Existing scientific knowledge concerning the effects of CO suggests that only health related impacts are of serious concern at or near ambient levels. Current medical research, however, is inadequate for benefits analysis because it does not provide a comprehensive understanding of exactly how low-level CO exposures adversely affect the body. At present, experimental evidence only demonstrates that cardiovascular patients experience early onset of angina when exposed to low levels of CO while exercising. Considerable additional research would be required to provide a better assessment of these and other CO-related health effects.

Because of the uncertainties described above involving CO health effects, EPA's approach to estimating benefits focuses on the number of

people and the number of occurrences of carboxyhemoglobin (COHb) levels of 2.1% or higher that are expected upon attainment of each alternative standard. Given the current state of knowledge, EPA believes that this measure is the most appropriate surrogate for estimating benefits associated with alternative CO standards.

The remainder of this section provides information in summary fashion on: (1) the mechanism of CO toxicity, (2) the nature of CO health effects and reported effects levels, (3) the population groups believed to be most sensitive to CO exposures and estimates of their size, and (4) the number of sensitive people and occurrences at or above 2.1% COHb upon attainment of alternative CO standards.

1. Mechanisms of CO Toxicity

The two principal sources of CO that contribute to levels of CO in the human body are: (1) endogenous CO production from the normal breakdown of hemoglobin constituents in the body and (2) inhalation of exogenous CO from ambient exposures.* Endogenous CO production contributes roughly 0.3 to 0.7 percent in the form of carboxyhemoglobin (COHb).

Presently, the most important mechanism of CO toxicity at low-level CO exposures is thought to be CO hypoxia. This mechanism generally involves diffusion of exogenous CO through the lungs into the blood with resultant formation of COHb. Such an increase in COHb levels disrupts normal delivery of oxygen to the tissues in two ways. First, CO displaces oxygen on the hemoglobin carrier so that the hemoglobin has a reduced capacity to carry oxygen through the blood to the tissues. Second, CO makes it more difficult for the oxygen that is still transported by hemoglobin to be released at the

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*The contribution of direct smoking to levels of CO in the body is not being considered as part of this rulemaking.

tissue. Under these conditions, the tissues must operate at lower than normal levels of oxygen, a condition known as hypoxia, and this amount of oxygen may be inadequate to meet the energy needs of the tissues. The effects of CO on the cardiovascular system, central nervous system, and other systems are thought to be directly related to this reduction in the ability of the blood to deliver oxygen to these systems and the resultant oxygen deficiency in the tissues themselves.

Other possible mechanisms of toxicity have been discussed (Coburn, 1979; EPA, 1984b). These alternative mechanisms involve binding of CO to such intracellular hemoproteins as cytochrome oxidase, myoglobin, tryptophan deoxygenase, and tryptophan catalase. Because the affinity constants for CO with these proteins are much less than that for hemoglobin, it is unlikely that they play a major role in CO hypoxia. However, in tissues with a high oxygen gradient between blood and tissue, it is reasonable to assume that the interaction of CO with these proteins (particularly with myoglobin in heart muscle) may play a role in CO toxicity. Myoglobin appears to facilitate the movement of oxygen through muscle cells and, as a short-term oxygen reservoir in muscle, it releases oxygen during sudden increased metabolic activity. The affinity of CO for myoglobin is about 40 times greater than the affinity of oxygen for myoglobin. The ratio of CO content in heart muscle to CO content in blood is approximately three. Therefore, given human exposure to CO, substantial amounts of CO may be stored in heart muscle. In situations of sudden, severe stress or exertion, the heart muscle's immediate oxygen supply may be inadequate, even in healthy persons and particuarly in persons with a history of disease. This alternative mechanism could provide theoretical support for experimental evidence of myocardial ischemia, such as electrocardiographic irregularities and decrements in work capacity discussed later

in this notice. However, it is not known whether binding of CO to myoglobin could cause health effects observed at COHb levels as low as 4-5 percent.

In summary, disruption of the normal transport of oxygen by formation of COHb in the blood appears to be the primary mechanism of CO toxicity. In addition, EPA concludes that regardless of the mechanism of toxicity, COHb levels provide a meaningful and useful physiological marker of CO toxicity and for estimating endogenous production of CO and exposure to exogenous sources of CO (EPA, 1984b).

2. Nature of CO Health Effects and Reported Effects Levels

Table 1 is a summary of key clinical studies reporting human health effects associated with low-level exposures to CO. This table is based on evidence discussed in the 1979 Criteria Document (EPA, 1979a) and in the Addendum (EPA, 1984b) but excludes a series of studies by Dr. Aronow for reasons given below. The table is included primarily as an aid for the following discussion and should be used only in conjunction with qualifying statements regarding the technical merits of each study made in the 1979 Criteria Document, in the Addendum, in the Staff Reassessment, or in the Federal Register notice for the final rule.

Cardiovascular Effects. In reviewing the primary standards, a principal area of concern to the Administrator has been evidence linking aggravation of angina and other cardiovascular diseases to CO exposures. Angina patients who have been exposed to low levels of CO while resting have subsequently exhibited, during exercise, reduced time to onset of angina (Anderson et al., 1973). In proposing to revise the CO standards, EPA viewed aggravation of angina, as reported above, to be an adverse health effect (45 FR 55066) and CASAC concurred with EPA's judgment on this matter.

TABLE 2. Lowest Observed Effect Levels For Human Health Effects Associated With Low Level Carbon Monoxide Exposure

Effects	COHb concentration (percent)[a]	References
Statistically significant decreased (~3-7%) work time to exhaustion in exercising young healthy men	2.3-4.3	Horvath et al., 1975 Drinkwater et al., 1974 Raven et al., 1974
Statistically significant decreased exercise capacity (i.e., shortened duration of exercise before onset of pain) in patients with angina pectoris	2.9-4.5	Anderson et al., 1973
Statistically significant decreased maximal oxygen consumption and exercise time during strenuous exercise in young healthy men	5-5.5	Klein et al., 1980 Stewart et al., 1978 Weiser et al., 1978
No statistically significant vigilance decrements after exposure to CO	Below 5	Haider et al., 1976 Winneke, 1974 Christensen et al., 1977 Benignus et al., 1977 Putz et al., 1976
Statistically significant impairment of vigilance tasks in healthy experimental subjects	5-7.6	Horvath et al., 1971 Groll-Knapp et al., 1972 Fodor and Winneke, 1972 Putz et al., 1976
Statistically significant diminution of visual perception, manual dexterity, ability to learn, or performance in complex sensorimotor tasks (such as driving)	5-17	Bender et al., 1971 Schulte, 1973 O'Donnell et al., 1971 McFarland et al., 1944 McFarland, 1973 Putz et al., 1976 Salvatore, 1974 Wright et al., 1973 Rockwell and Weir, 1975 Rummo and Sarlanis, 1974 Putz et al., 1979 Putz, 1979
Statistically significant decreased maximal oxygen consumption during strenuous exercise in young healthy men	7-20	Ekblom and Huot, 1972 Pirnay et al. 1971 Vogel and Gleser, 1972

[a]The physiologic norm (i.e., COHb levels resulting from the normal breakdown of hemoglobin and other heme-containing materials) has been estimated to be in the range of 0.3 to 0.7 percent (Coburn et al., 1963).

One controlled human exposure study (Anderson et al. 1973) reported that experimental subjects with angina exhibited statistically significant reduced time to onset of exercise-induced angina after exposure to low levels of CO resulting in mean COHb levels of 2.9 (range 1.3-3.8 percent) and 4.5 percent (range 2.8-5.4 percent). There remain some concerns about the study findings due to ambiguities regarding the design and conduct of the study and the small number of subjects (N=10) examined. However, as discussed in the Addendum, a reevaluation of the Anderson et al. (1973) study addressing major points of concern, found that the study provides reasonably good evidence for the hastening of angina occurring in angina patients at COHb levels of 2.9 to 4.5 percent.

Another cardiovascular effect of concern is the possible detrimental effect of increased blood flow that occurs as a compensatory response to CO exposure (Ayres et al., 1969; Ayres et al., 1970; and Ayres et al., 1979). This effect may be related to coronary damage or cerebrovascular effects at very high blood flow rates due to the added stress on the cardiovascular system. However, community epidemiological studies have been inconclusive. In particular, based on EPA's evaluation of the Goldsmith and Landau (1968), Kurt et al. (1978), and Kurt et al. (1979) epidemiological studies, the relationship between CO exposures and effects such as mortality from myocardial infarction (heart attack), sudden death due to arteriosclerotic heart disease, and cardiorespiratory complaints remains in question.

Maximum aerobic capacity and exercise capacity are indirect measures of cardiovascular capacity which have been reported to be reduced in several carefully conducted studies involving normal healthy adults exposed

to CO. A linear decline in maximum aerobic capacity for healthy individuals was reported for COHb levels ranging from 5-20 percent in a series of studies (Stewart et al., 1978; Weiser et al., 1978; and Ekblom and Huot, 1972). Horvath et al. (1975) found decreases in maximum aerobic capacity when COHb levels were 4.3 percent and that COHb levels of 3.3 and 4.3 percent reduced work time to exhaustion by 4.9 and 7.0 percent, respectively. The effects of lower CO exposure levels in healthy individuals have also been investigated under conditions of short-term, maximum exercise duration. In a series of studies involving different CO exposure levels, two alternative ambient temperatures (25°C and 35°C), and two different healthy adult populations (young and middle-aged), no statistically significant reduction in maximum aerobic capacity was observed for either group when CO exposures were compared with the clean air control. However, small (less than or equal to 5 percent) decreases in absolute exercise time were consistently observed in the non-smoking subjects whose COHb levels reached 2.3 and 2.5 percent (Drinkwater et al., 1974; Raven et al., 1974). These effects, while not as serious as aggravation of angina, are still a matter of concern since they have been found to occur in healthy individuals and such effects might impair the normal activity of more sensitive populations. Therefore, these effects have been considered in judging which CO standards provide an adequate margin of safety.

Central Nervous System Effects. Numerous studies (Putz et al., 1976; Bender et al., 1971; Schulte, 1973; O'Donnel et al., 1971; McFarland et al., 1944; McFarland, 1973; Salvatore, 1974; Wright et al., 1973; Rockwell and Weir, 1975; and Rummo and Sarlanis, 1974) have reported effects on the central nervous system for CO exposures resulting in COHb levels in the range 5-17 percent. The range of effects reported included impairment of vigilance, visual perception, manual dexterity, learning ability, and performance of complex

tasks. While one study (Beard and Grandstaff, 1975) has suggested that vigilance effects may occur at levels as low as 1.8 percent COHb, several other studies (Haider et al., 1976; Winneke, 1976; Christensen et al., 1977; Benignus et al., 1977; and Putz et al., 1976) have not found any vigilance decrements below 5 percent COHb. Measurement methods used to detect effects may have been too insensitive to detect changes in the latter vigilance studies. Based on the assessment of the above mentioned studies, the Addendum, concluded that, at least under some conditions, small decrements in vigilance occur at 5 percent COHb. A series of studies (Putz et al., 1976; Putz et al., 1979; and Putz 1979) has also found that 5 percent COHb produced decrements in compensatory tracking, a hand-eye coordination task. EPA considers hand-eye coordination effects as well as decrements in vigilance to be important since these functions are components of more complex tasks, such as driving, and reduced alertness or visual sensitivity could lead to increased vehicular accidents.

Fetal Effects. Based on the limited animal toxicology data, the 1979 Criteria Document (EPA, 1979) and the Addendum (EPA, 1984b) suggest that CO may produce effects on the fetus or newborn. Long-term exposures to CO may result in a slower elimination of CO by the fetus and may lead to interference with fetal tissue oxygenation during development. Because the fetus may be developing at or near critical tissue oxygenation levels, even exposures to moderate levels of CO may produce deleterious effects on the fetus such as reduced birth weight and increased newborn mortality (Longo, 1977), although this remains to be demonstrated alone with pertinent dose-response relationships (EPA, 1984b). Evidence from smoking mothers is suggestive of similar fetal and newborn effects due to CO exposures (Peterson, 1981). While the fact that cigarette smoke contains substances other than CO prevents a direct

quantitative application of the results of these studies in setting the CO primary standards, these studies do suggest the need for caution in protecting unborn children from such potentially deleterious effects of CO exposures.

As discussed in the Addendum and Staff Reassessment, research on sudden infant death syndrome (SIDS) recently has suggested a possible link between ambient CO levels and increased incidence of SIDS (Hoppenbrowers et al., 1981). It has been pointed out by Goldstein (1982) that indoor sources of CO, as well as other pollutants (e.g., nitrogen dioxide, lead), may be at least as important as ambient CO in causing SIDS and that the relationship between SIDS and ambient pollution levels may be only coincidental. Because the number of potentially confounding factors makes finding an association between CO and SIDS extremely difficult, further confirmation is needed before any causal relationship can be inferred (EPA, 1984a; EPA, 1984b).

3. Sensitive Population Groups

In EPA's judgment, the available health effects data identify persons with angina or other types of cardiovascular disease (e.g., history of heart attack) as the groups at greatest risk from low-level, ambient exposures to CO. Based on 1980 census data (DOC, 1980) and earlier U.S. National Health Examination Survey data (DHEW, 1975), this group is estimated to number approximately 8.7 million individuals or approximately 5.0 percent of the adult population. As discussed previously, the concern for persons with cardiovascular disease results from the fact that their condition is due to an insufficient oxygen supply to cardiac tissue, so that persons with this condition have an inadequate oxygen reserve capacity and an impaired ability to compensate for the effects of excess CO.

The Addendum and Staff Reassessment also identify several other groups as likely to be particularly sensitive to low-level CO exposures based on

EPA's review of the health effects evidence. These groups include: (1) persons with chronic respiratory disease (e.g., bronchitis, emphysema, and asthma), (2) elderly individuals, especially those with reduced cardiopulmonary function, (3) fetuses and young infants, and (4) individuals suffering from anemia and/or those with abnormal hemoglobin types that affect oxygen carrying capacity or transport in the blood. In addition, individuals taking certain medications or drinking alcoholic beverages may be at greater risk for CO-induced effects based on some limited evidence suggesting interactive effects between CO and some drugs. Visitors to high altitude locations are also expected to be more vulnerable to CO health effects due to reduced levels of oxygen in the air they breathe. Finally, individuals with some combination of the disease states or conditions listed above (e.g., individuals with angina visiting a high altitude location) may be particularly sensitive to low-level CO exposures, although there is no experimental evidence to confirm this hypothesis.

Table 3 briefly summarizes the rationale for the judgments that these groups are more likely to be affected by low-level CO exposures and presents population estimates for each group. For most of the groups listed in Table 2 there is little specific experimental evidence to clearly demonstrate that they are indeed at increased risk for CO-induced health effects. However, it is reasonable to expect that individuals with preexisting illnesses or physiological conditions which limit oxygen absorption into blood or its transport to body tissues would be more susceptible to the hypoxic (i.e., oxygen starvation) effects of CO.

Table 3. Summary of Potentially Sensitive Population Groups[a]

Group	Rationale	Population Estimates	Percent of Population	Reference
Coronary Heart Disease	Anderson et al. (1973) suggests reduced time until onset of exercise-induced angina in 2.9-4.5% COHb range.	8.7 million (in 1980)	5.0 (of the adult population)	DHEW, 1975 DOC, 1980
Angina Pectoris		7.0 million (in 1980)	4.0 (of the adult population)	
Chronic Obstructive Pulmonary Diseases	Reduced reserve capacities for dealing with cardiovascular stresses and already reduced oxygen supply in blood likely to hasten onset of health effects associated with CO-induced hypoxia.			DHEW, 1973
Bronchitis		6.5 million (1970)	3.3	
Emphysema		1.5 million (1970)	0.7	
Asthma		6.0 million (1970)	3.0	
Fetuses and Young Infants	Several animal studies (Longo, 1977) report deleterious effects in offspring (e.g., reduced birth weight, increased newborn mortality, and lower behavioral activity levels).	3.1 million live births/year (1975)		DHEW, 1978
Anemia	Oxygen carrying capacity of blood is already reduced increasing likelihood of CO-induced hypoxia effects at lower CO exposure levels than for non-anemic individuals.	3.0 million (1973)	1.4	DHEW, 1977
Pernicious and Deficiency Anemias		.15 million (1973)	0.07	
Peripheral Vascular Disease	Reduced oxygen-carrying capacity to limbs likely to hasten onset of health effects associated with CO-induced hypoxia.	0.75 million (in 1979)	0.3	DHEW, 1974
Elderly	CO exposures may increase susceptibility of elderly individuals to other cardiovascular stresses due to already reduced reserve capacities to maintain adequate oxygen supply to body tissues.	24.7 million (in 1979) > 65 years old		DOC, 1980

[a]All subgroups listed are not necessarily sensitive to CO exposure at low levels.

3. Sensitive Population Exposure Estimates for Alternative Standards

Objective. An important element in assessing alternative air quality standards is an assessment of the population exposure to pollutant concentrations that would result if a given standard were just attained. Particularly important is an assessment of exposures for the most sensitive people. EPA's revised exposure analysis report and addendum, "The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide," (Johnson and Paul, 1983; Paul and Johnson, 1985) contain estimates of the numbers and percentage of urban American adults with cardiovascular disease that would be exposed to various ambient CO levels if alternative 8-hour CO standards were just attained. In addition, estimates have been made of the percentage of this population that would exceed selected COHb levels each year. These latter estimates were derived by applying the Coburn model, which relates patterns of CO exposure to resultant COHb levels, to the exposure model outputs using a typical set of physiological parameters for adult men and a separate set of physiological parameters for adult women.

Both CO exposure estimates and COHb level estimates have been made for four urban study areas. Both types of estimates have also been made for the total urban United States population, by extrapolating the four urban study area estimates.

A brief description of (1) the exposure model used to make the exposure estimates, (2) the model used to calculate COHb levels from patterns of CO exposure, and (3) the method of extrapolating these estimates to the whole urban U.S. sensitive population are presented in the following paragraphs.

Description of Exposure Model. The exposure of an individual to an air pollutant may be quantitatively expressed by giving the duration of the

exposure and the average concentration of the pollutant in the immediate vicinity of the individual during the exposure period. The time periods of exposure that are of interest for CO are one and eight hours. The exposure of a population to CO can be described by giving the total number of one hour exposures to concentrations at or above given values for a range of concentrations from zero to the highest exposure concentrati on observed. This is the cumulative distribution of one hour exposures. A similar distribution can be given for eight hour exposures. For either one or eight hour exposures the total number of possible exposures in one year is the product of the population and the total number of hours in one year.

Another measure of exposure is provided by counting the number of people who experience a given one or eight hour average concentration or higher at least once during the year. A third measure is the number of people for whom a given one or eight hour average concentration is the highest concentration experienced in a one year period. The first two measures are in the form of cumulative distributions. The third measure is in the form of a density function.

The exposure model is used to estimate all three exposure distributions for a given geographical area, either for an existing situation or under hypothetical conditions in which the area is just in compliance with a given NAAQS. To estimate exposure when an area is just in compliance with a given NAAQS, the exposure model proportionally adjusts CO concentrations observed at each of several selected monitors. Air quality indicators are derived from the data base of ambient CO concentrations for each hour throughout a given year. The CO concentrations are proportionally adjusted so that the adjusted air quality indicator for the monitor with the highest CO concentrations would be just in compliance with the given NAAQS. Hence,

the concentrations at other monitors are adjusted to levels that are generally lower.

The exposure model apportions the population of a given area among a number of cohorts (up to 300 in this application). Twelve age/occupation categories are each subdivided into several smaller subcategories. A single cohort represents all individuals of a given subcategory living in the same type of neighborhood. Each hour of the calendar year a given cohort is located in a particular neighborhood type and microenvironment and engaged in some level of exercise. Assignment of individual cohorts to neighborhood type, microenvironment, and exercise level for each hour is made by using general data on human activity patterns and transportation data for the area under study. The manner in which this is done is discussed in detail elsewhere (Biller et al., 1981; Johnson and Paul, 1983).

An important feature of the exposure model is the way it partitions concentrations, people, place, and time into discrete groupings or segments. Microenvironments are an important example of this feature (Duan, 1981). The infinite number of possible places contained within a geographical area where people are exposed to air pollutants is represented by a finite number of types of environments where pollutant concentrations tend to be relatively homogenous. The microenvironments are defined such that an individual is always assigned to one of five microenvironment types: (1) work-school, (2) home and other indoor, (3) inside transportation vehicle, (4) roadside, and (5) other outdoor. Transformations are made of base concentrations derived from the fixed monitoring system in order to estimate concentrations to which people would actually be exposed in the microenvironments. Values for the multiplicative transformation factors

that would give the best exposure estimates are uncertain. The values used for these factors were estimated making use of the available literature on (1) indoor and inside-motor-vehicle air pollution and (2) statistical analyses of monitoring data (e.g., how ambient values change with height and distance from a monitor). These estimates are made for conditions under which the monitoring system is indicating compliance with various standards. For example, the transformed value of the concentration inside a vehicle is higher than the base value derived from the monitoring system because studies have shown that in general this is the case; the transformed value in the other outdoor (away from roads) microenvironment is lower, as has also been found in exposure research.

Obviously, the division of the day into a set of twenty-four one-hour periods is an abstraction which only approximates actual human activity. For example, if a person is driving a vehicle ten minutes and is indoors fifty minutes between 2:00 p.m. and 3:00 p.m. the model would have him indoors the whole hour. Thus, the assumptions made are reasonable modeling assumptions, not a perfect depiction of reality.

An air monitoring station is associated with each neighborhood type to estimate exposure concentrations for each neighborhood type-microenvironment combination. The hourly average CO concentration observed at the monitor each hour of the year is the concentration associated with the neighborhood type each hour of the year. This concentration is further transformed to take into account the microenvironment, additional contributions from indoor sources, and the particular NAAQS specification. The result is the exposure concentration that is associated with each neighborhood type-microenvironment combination each hour of the year.

By accounting for the whereabouts of each cohort each hour of the year in terms of the neighborhood type-microenvironment and making appropriate use of air monitoring data it is possible to follow the hour by hour exposure of each cohort throughout the year. The model performs the needed transformations of the concentration for each NAAQS designation and calculates the three exposure distributions described earlier (total exposures, people exposed, peak exposures) for one hour exposures and for running eight hour exposures over the calendar year.

Since the model accounts for the hour by hour exposure of each cohort, it is possible to compute the COHb level at the end of each hour for each cohort by applying the Coburn model (Coburn, 1965) to the exposure model outputs. The Coburn model relates CO exposure to COHb levels, given appropriate physiological parameters for each cohort of the sensitive population. Physiological parameters are estimated for each sex and for the age/occupation category of each cohort on the basis of literature data.

Extrapolation to U.S. Urban Population. The exposure model described in the preceding paragraphs is directly applicable to a particular urbanized area. To apply it to the total urban population area of the U.S. would require that the model be run for each urbanized area in the U.S. and the exposures in each applicable pollutant concentration range be added together. Since such a procedure would have required a major effort, an estimate of the sensitive urban adult population exposures to CO and resulting COHb levels was made by extrapolation. The extrapolation was based on exposures estimated by application of the model to four urbanized areas: Chicago, Los Angeles, Philadelphia, and St. Louis. The extrapolation procedure was as follows: Each urbanized area within the U.S. with population greater than 200,000 was associated with one of the above mentioned four urbanized

areas. The association was made on the basis of proximity, average wind speed, peak CO concentrations, observed climate, and general character of the area. By summing the populations of each of the areas associated with a given base area, including the population of the base area, it was possible to estimate the sensitive urban population associated with each of the four base areas.

To apply the population exposure estimates associated with each of the four base areas to the nation, it was first necessary to normalize the CO exposure and COHb distributions obtained for the sensitive group in each base area by converting the distributions to a per person basis. These distributions were each multiplied by their respective associated, sensitive, U.S.-wide, urban population values and summed over the four cities to obtain the extrapolated distributions.

Results. Selected results are presented in Tables 4 and 5. Estimates of the number of sensitive people in the urban U.S. whose COHb levels would exceed various selected concentrations upon attainment of four alternative NAAQS are presented in Table 4. The four situations assume that the alternative standards are just met in each urban area of the U.S. It is anticipated that air quality in a number of urban areas will be superior to that required to meet the standards given in the tables due to nationwide control programs such as the FMVCP.

Table 4 provides estimates for 1987 of the percentage of the adult population living in urban areas who would exceed various COHb levels upon attainment of three alternative 8-hour standards. For example, less than 0.01 percent of the adult population in urban areas is estimated to exceed 2.1 percent COHb due to CO exposures associated with attainment of the current (deterministic) 9 ppm standard, and approximately 20 percent of the adult

Table 4. Cumulative Percentage of Cardiovascular Adult Population in Urban Areas Whose COHb Levels Would Exceed Specified COHb Values Upon Attainment of Alternative 8-Hour Standards[a,b,c]

	8-Hour Standards			
	9 ppm 1 Observed Exceedance	9 ppm 1 Expected Exceedance	12 ppm 1 Expected Exceedance	15 ppm 1 Expected Exceedance
COHb Level Exceeded (Percent)				
3.0		-	.01	1.1
2.9		-	.02	2.5
2.7		-	0.1	5.9
2.5		-	0.8	9.7
2.3		0.01	4.1	14
2.1	<.01	0.1	8.6	20

[a]Projected cardiovascular disease population in all urbanized areas in the United States for 1987 is 5,240,000 adults.

[b]These exposure estimates are based on air quality distributions which have been adjusted to just attain the given standards.

[c]These exposure estimates are based on best judgments of microenvironment transformation factors. Projections for one urban area based on lower and upper estimates of the microenvironment transformation factors are provided in the Exposure Analysis report (Johnson and Paul, 1983).

Table 5. Estimates of Number of Occurrences Among Cardiovascular Adults in Urban U.S. of Carboxyhemoglobin Levels Exceeding Selected Concentrations Upon Attainment of Alternative 8-hour Standards[a]

	8-Hour Standards			
	9 ppm 1 Observed Exceedance	9 ppm 1 Expected Exceedance	12 ppm 1 Expected Exceedance	15 ppm 1 Expected Exceedance
COHb Level Exceeded (Percent)				
3.0		-	570	106,000
2.7		-	14,800	810,000
2.5		-	76,700	1,880,000
2.3		570	473,000	4,100,000
2.1	-	12,000	1,580,000	8,580,000

[a]It is estimated that the total number of occurrences for the sensitive population in urban areas in 1987 will be 45,900,000,000 (approximately 5,240,000 sensitive people times 8,760 8-hour periods per year)

population is estimated to exceed 2.1 percent COHb upon attainment of a 15 ppm standard with 1 expected exceedance allowed per year. It should be noted that the estimates given in Table 4 are based on air quality distributions which have been adjusted to just attain the given standards.

The urban population of the United States consists of people living in urbanized areas of the country. Urbanized areas consist of all cities of 50,000 population or more and their contiguous incorporated places. It is estimated that this population will be 142 million in 1987 (based on a 1% annual growth rate). It is further estimated that approximately 110 million of these individuals will be adults (over age 18). Approximately 5.8% of the adult male population and approximately 4.2% of the adult female population have angina or other coronary heart disease (DHEW, 1975). It is estimated that approximately 52% of the adult population will be female. Consequently, it is estimated that the size of the most sensitive population residing in urban areas will be approximately 5.2 million in 1987.

Estimates of the percentage of the urban U.S. sensitive population whose COHb levels would exceed various selected concentrations are presented in Table 4. For example, it is estimated that the percentage of the sensitive population that would experience a COHb concentration exceeding 2.1% at least once due to exposure to CO if the 9 ppm, 1 observed exceedance standard were just met throughout the urban United States in 1987 is less than 0.01%.

The estimated number of COHb concentration occurrences in 1987 exceeding various COHb levels is presented in Table 5. The number of occurrences differs from the number of people in that if the same person exceeds a

given COHb level N times it counts as N occurrences. One occurrence occurs every time a person's COHb level exceeds the given concentration at the end of an hour. For example, if a 9 ppm, 1 expected exceedance standard is just attained, the number of occurrences where COHb levels exceed 2.1% is estimated to be 12,000 while the number of people exceeding 2.1% COHb is approximately 5,200. Thus, the number of occurrences is more than twice the number of people due to multiple occurrences.

Uncertainty. Several factors make the accuracy of the nationwide exposure estimates uncertain. They include: (1) the paucity of information on several of the needed inputs (e.g., some of the microenvironment multiplicative transformation factors) and (2) the fact that nationwide estimates were extrapolated from only four urbanized areas.

Ideally, the uncertainty in each significant uncertain factor would be addressed formally (probabilistically) within the exposure model so that a formal (probabilistic) representation of the uncertainty in each exposure estimate would be part of the output of the model. In the future the NAAQS Exposure Model (NEM) will be developed further into a probabilistic model (Biller et al., 1981). Due to limitations of time and resources a less extensive approach designed to obtain a rough estimate of the degree of uncertainty has been used in the present study.

In this application of a NEM a limited analysis has been done of the sensitivity of the exposure estimates to variations in some of the most uncertain inputs. Lower and upper estimates were made of the quantities whose uncertainty had the largest impact on the estimates, namely, the factors used to transform monitored CO concentrations to estimates of CO concentrations to which people are actually exposed in the various micro-environments. NEM was applied to one city (Chicago) for one standard

(12 ppm, 1 Ex Ex) using the lower and upper estimates. The results of this application are presented in Tables 7-40 through Table 7-44 of the more detailed report of the CO exposure analysis (Johnson and Paul, 1983). It is clear from the large disparity between the lower and upper estimates presented in these tables that the uncertainty about the best values for these transformation factors alone leads to significant uncertainty about the accuracy of the exposure estimates.

Two of the physiological parameters which determine COHb levels in the blood resulting from given patterns of CO exposure are another source of uncertainty investigated via a limited sensitivity analysis. The results of a limited variation in the values assigned the Haldane constant and the low exercise level ventilation rate are presented in Table 7-45 of the exposure report. These variations have a significant effect, but not as large an effect as the variation in estimated microenvironment factors.

Obviously, sensitivity analysis runs in which microenvironment transformation factors and physiological parameters were varied together would result in even more widely divergent estimates. Also, other uncertain factors and the uncertainty introduced in the nationwide extrapolation have not been addressed in these limited analyses. In sum, the exposure estimates are as good as can be made given the state of the art, but their accuracy is quite uncertain.

V. COST ANALYSIS

A. Introduction

This chapter emphasizes the direct principal, or real-resource, costs associated with controlling emission sources of carbon monoxide (CO) air pollution in order to attain alternative national ambient air quality standards. These costs were estimated for 3 years--1987, 1990, and 1995. Only the 1995 results are discussed here. The costs are in constant 1984 dollars unless otherwise noted. Cost estimates are derived from an EPA report entitled Cost and Economic Assessment of Alternative National Ambient Air Quality Standards for Carbon Monoxide (Revised) (EPA, 1985).

The above report contains a number of detailed cost and economic analyses that are not reproduced here. These include an investigation of the impacts of setting alternative CO standards on specific population income groups (all income categories), industrial sectors, local governments, and small businesses. Major findings from these specialized studies are:

1. no particular segment of the population is forced to pay a disproportionate amount of the total cost of mobile source control. Therefore, there are no significant adverse income distribution impacts associated with any of the alternative CO standards.
2. while "distressed cities" are definitely affected by various CO control programs, the probable overall impact on local government finances is considered to be negligible. The prime reason for this conclusion is that most of the direct costs of CO control programs are borne by motor vehicle owners and users, not by local governments. Inspection and maintenance programs are self-supporting, paid by for user fees; transportation control measures are partly paid for by the federal government under a U.S.

Department of Transportation progran intended to reduce energy consumption associated with motor vehicle use.

3. small businesses are not affected directly by CO capital and operating expenditures, because no small business as defined by Small Business Administration criteria will be required to install air pollution controls to attain the ambient CO standards investigated.
4. financial capital is generally available for those few large industrial sources that need to install CO pollution control. Major shifts in the firms' opportunity cost of capital are not anticipated. For all but 2 or 3 firms in the country, CO capital expenditures are less than 5% of projected capital expenditures. In no case are CO capital expenditures larger than 8% of projected capital expenditures.
5. for affected industries and plants, controls associated with the alternative standards are judged to be economically affordable. No significant product output adjustments are anticipated in response to product price changes, which should be quite small for all alternative standards (less than 0.5% in most cases).

The interested reader is referred to EPA (1985) for more information on the items discussed above.

As discussed in the above reference, the methodology used to estimate regulatory impacts associated with alternative CO standards is highly sensitive to the value used to represent air quality in the base year (the so-called design value). A small change in this value can substantially alter non-attainment area projections and the amount of control theoretically needed in a particular location. Similarly, other assumptions such as the

form of the standard (i.e., statistical or discrete) growth rates, and base year of the emissions inventory can affect predicted attainment and cost projections.

Cost projections also are affected by the nature and timing of the control strategy program assumed for an area. Numerical criteria were developed based on the percent of emission reductions needed in an area to determine what mix of CO strategies were assumed in that area. These strategies, such as inspection and maintenance programs and transportation control measures, were applied and costed out to determine national CO costs. It should be recognized that the devised programs are hypothetical. Actual control programs are developed by state and local air quality management agencies in the state implementation planning process. Actual national costs of CO control programs will be the sum of many individual state decisions, not the hypothetical program developed for this regulatory impact analysis.

For purposes of this regulatory analysis, no fuel savings benefit is claimed for factory installed automobile carbon monoxide control equipment.*

B. RACM Control Costs

CO control equipment and strategies are divided into two major types.

1. reasonably available control measures (RACM).
2. best available control measures (BACM).

Reasonably available control measures and technologies are the principal mechanisms in state implementation plans which are developed to attain and maintain a national ambient air quality standard. For this reason, RACM control costs are the main focus of interest in this Regulatory Impact

*However, fuel economy savings are claimed for some of the control measures that go beyond automotive hardware. See below.

Analysis. However, as will be discussed in more detail later, some areas may require more control, or more stringently enforced control, than RACM to attain a particular standard.

RACM control strategies include "normally operated" inspection and maintenance programs for automobiles (I&M), transportation control measures (TCM) oriented toward increasing mass transit ridership and improving traffic movement, and point source-oriented technologies. (See EPA, 1979 and its backup material for more information on specific RACM strategies that were investigated.) Total national annualized costs associated with these RACM strategies for 1995 are depicted in Table 6. All estimates are in constant 1984 dollars. The geographic unit of interest for the most part is a Standard Metropolitan Statistical Area (SMSA) as defined by the U.S. Census Bureau.

Table 6 also includes an estimate of the number of SMSAs that cannot attain the alternative standards in 1995 with the use of RACM control strategies. As can be seen, all SMSAs can attain the 12 and 15 ppm standards in 1995 but that is not true for the other alternatives.

Automobile and other mobile source emissions controls are required by Title II of the Clean Air Act (42 U.S.C. 7501, et seq.), and are not affected by alternative ambient air quality standards. (Title II is also called the federal motor vehicle control program, or FMVCP.) Thus, for any particular emission standard, FMVCP costs are identical in any single year for the four ambient CO standards investigated--9 ppm, second-high 8-hour average observed value (9/2; this is also called the one observed exceedance standard, but to avoid a wordy nomenclature, it is designated as the 9/2 standard); 9 ppm, one expected exceedance of the daily maximum standard (9/1); 12 ppm, daily maximum one expected exceedance standard (12/1); and

Table 6. Annualized 1995 RACM Control Costs for Four Alternative CO NAAQS[a]

(1984 10^6)

Control Item	Alternative NAAQS Standard (ppm/expected exceedances)			
	9 ppm 2nd-High	9/1	12/1	15/1
FMVCP	4,430	4,430	4,430	4,430
Additional Mobile[b]				
I&M	232	198	48	32
TCM	53	27	4	-2
Stationary Sources[c]	27	27	31	16
Total RACM Costs	4,742	4,682	4,513	4,476
Residual Non-Attaining Areas	3	2	0	0

Notes: [a]For the "primary case;" see EPA 1985. There are no fuel savings (benefits) assumed for the FMVCP program.

[b]Additional mobile source controls include fuel savings credits.

[c]Stationary sources controls include fuel savings credits; the modeling approach used cannot distinguish between "forms" of alternative standards, which accounts for the same number being used for the two 9 ppm standards.

15 ppm, one expected exceedance of the daily maximum standard (15/1). This is shown in Table 6. The FMVCP standard assumed throughout this report is 3.4 grams per mile.

FMVCP costs are not directly associated with a CO ambient air quality standard. Incremental costs associated with changing air standards are those relating to different levels of I&M, TCM, and stationary source programs hypothetically needed in areas which require more control to attain a given NAAQS than can be achieved through FMVCP alone.* Even though the FMVCP cost is not directly attributable to the CO ambient standards investigated, its cost is shown in Table 6. All subsequent discussions concerning total costs to attain the CO ambient standard include that portion of the FMVCP program associated with CO emission standards.

Control costs associated with industrial stationary sources of CO emissions are relatively minor. For the 9 ppm standards, both the 2nd-high and one expected exceedances, these costs are estimated to be $27 million in 1995. (This estimate includes fuel savings from the use of CO boilers or incinerators with primary and secondary heat recovery), two heat-producing, readily available CO control techniques.) For the 12 ppm, 1 exceedance standard, control costs increase to $31 million, reflecting less fuel savings in those industries with negative annualized costs of controlling CO.** CO control

*Likewise, costs of new source performance standards (NSPS) should not be attributed to the CO NAAQS since that program is required by another section (111) of Title I of the Clean Air Act (42 U.S.C. 7409). The NSPS program is small for CO. Only two process categories are affected by a CO NSPS: catalytic cracker and submerged arc furnace. Neither category incurs a negative cost due to fuel savings associated with the CO NSPS (EPA, 1985).

**Of the seven industrial categories that have plants theoretically needing CO controls to attain alternative ambient standards, four have negative annualized costs due to fuel savings potential. The categories are maleic anhydride, carbon black, steel, and automobile manufacturing. Industrial categories incurring positive costs include gray iron, primary aluminum, and incineration. It is estimated that, at most, only 29 plants in the country may be required to install air pollution controls to meet the alternative CO NAAQS investigated. See EPA (1985) for more information.

costs drop for stationary sources in 1995 for the 15/1 standard because many fewer plants hypothetically have to install controls in the first place.

The remainder of the costs shown in Table 6 refer to area-specific mobile source programs designed to reduce CO emissions from in-use vehicles. Two general types of programs are depicted: inspection and maintenance (I&M) programs focused on so-called light-duty vehicles (passenger automobiles and small trucks) and transportation control measures (TCM). In the theoretical cost analysis, the type and timing of these programs varied widely throughout the country, depending upon:

1. location of the urbanized area being analyzed. California areas were treated differently than the rest of the country, because they have different base-year emission factors and different I&M effectiveness ratios. The same is true for high altitude areas.
2. status of current I&M programs and status of I&M legislation in the state containing the urbanized area being studied. These considerations affected the hypothetical start date used in the cost analysis.
3. the number of vehicles failing an I&M program. This is called the "stringency factor."
4. the particular mix of local and area TCM's used, and whether or not these were sufficient to attain the CO standard without an I&M program.

Because of these variables, it is difficult to generalize and discuss what sets of I&M/TCM programs were used in the cost analysis. The interested reader is referred to the Cost and Economic Analysis (EPA, 1985) and its backup report (Siddiqee, 1979) for more information.

C. Alternative Control Strategies and Their Costs

The cost data presented in Table 6 are for a "primary case" scenario and RACM control strategies. As can be seen, not all areas can attain the 9/2nd-high and 9/1 ExEx alternative NAAQS in that case. It is theoretically possible to attain all but the 9/2nd-high standard in 1995 by using additional hypothetical control strategies or by making different analytic assumptions.

Four alternative cases were investigated. They are:

1. 40% I&M Stringency. This case differs from the primary case only in increasing the stringency factor, or rejection rate of the I&M program from a previous arbitrary maximum of 30% to a new maximum of 40%. (This does not mean that all SMSAs used a 40% rejection rate. Only those areas that could not hypothetically attain with a 30% program and had more than 5% in residual overall emissions reductions left to go, were assigned a 40% stringent I&M program.) Effectiveness of this technique varied by the length of time an I&M program was assumed to be operating* and whether an area was in California, in a high altitude area, or in the rest of the country. The extra emissions reductions obtained via this increase in rejection rate varied between 4% and 5%, depending upon the factors noted above (SRI International, 1979).

2. 100% I&M Effectiveness. This case assumed that I&M would be 100% as effective in reducing emissions from post-repaired vehicles in cold weather areas as it is in warm weather areas. The primary case assumed I&M was 50% effective in areas with a November-January temperature of 20°F or below, and 100% at said temperature of 70°F or above. (Inbetween temperatures

*I&M programs were assumed to start in 1984, 1985, or 1986 depending upon the legal status of I&M legislation in a state and local progress toward implementing such a program. see Siddiqee, et al. (1979).

Table 7. Range in Annualized 1995 Control Costs for Four Alternative CO NAAQS

(1984 10^6)

	Alternative NAAQS Standard (ppm/expected exceedances)			
	9 ppm 2nd-High	9/1	12/1	15/1
Case 1. 40% I&M Stringency				
Additional Mobile	311	219	53	33
Stationary Sources	27	27	31	16
Total Variable Costs	$338	$246	$84	$49
Residual Non-Attain. Areas	3	2	0	0
Case 2. 100% I&M Effectiveness				
Additional Mobile	261	221	43	33
Stationary Sources	27	27	31	16
Total Variable Costs	$288	$248	$74	$49
Residual Non-Attain. Areas	1	0	0	0
Case 3. 1 ppm Background				
Additional Mobile	297	239	43	28
Stationary Sources	27	27	31	16
Total Variable Costs	$324	$266	$74	$44
Residual Non-Attain. Areas	7	4	0	0
Case 4. 1984 Base Year				
Additional Mobile	338	263	73	42
Stationary Sources	27	27	31	16
Total Variable Costs	$365	$290	$104	$58
Residual Non-Attain. Areas	10	6	0	0

	Incremental Costs Range for Alternative NAAQS		
	9/2 to 9/1	9/1 to 12/1	12/1 to 15/1
Costs (x 10^6)	$40-$75	$174-$192	$30-$46

D. Transaction Costs (Secondary Costs)

According to guidance on performing regulatory impact analyses, a complete cost analysis of major governmental actions contains an evaluation of certain secondary costs associated with that action. These include governmental regulatory costs, adjustment costs for unemployed resources, and costs associated with adverse effects on market structure, innovation, and productivity. Most of these items were not specifically investigated in the cost and economic assessment (EPA, 1985) underlying this Regulatory Impact Analysis. Consequently, what follows is a general qualitative discussion of the secondary costs enumerated above.

1. Governmental Regulatory Costs

Costs incurred by governments related to the CO NAAQS depend upon the role each governmental agency plays in the federal-state system air resource management established by the Clean Air Act. As regards a NAAQS, EPA provides scientific and technical analyses in developing, reviewing, and setting air standards. It also provides technical support in developing and maintaining computerized national data systems that store ambient air quality and emissions data. Finally, EPA provides technical guidance to the states in operating and reporting ambient monitoring networks, developing state implementation plans, and undertaking enforcement actions against certain violators of the state's own rules and regulations.

It is extremely difficult to separate out that part of the total costs for these functions attributable to carbon monoxide, since it is only one of seven NAAQS and numerous other pollutants that are more or less handled simultaneously by EPA in performing the functions noted above. However, EPA's costs to review the CO NAAQS and promulgate a revised standard can be

estimated. The items covered include: (1) scientific review of health literature and development of the CO criteria document, (2) review of existing ambient data to determine potential problem areas, (3) development of a set of control strategies, which are then costed out, (4) analysis of the economic impacts associated with these costs, (5) analysis of exposures to alternative CO standards, (6) development of the regulatory package for proposal and promulgation, (7) analysis of public comments, and (8) internal review of the various regulatory documents. EPA's estimated total costs for CO for these items are:

1. 14 person years of staff time.
2. $1,160,000 of contract funds.
3. $60,000 of computer time.

This comes to a total of approximately $2.5 million (in 1984 dollars). It is a one-time cost* that occurred over 6 fiscal years. This estimate does not include any costs of maintaining CO air quality or emissions inventory data. It also does not include any guidance activities costs. The problem of costing these activities is difficult as data do not exist to exactly apportion total costs of these activities to CO. However, they are estimated to be an order-of-magnitude lower than the cost incurred to review and set the standard.

States, and, if they so delegate, local governments, actually implement Clean Air Act provisions directed toward attaining and maintaining NAAQS. Their major implementing functions include operating air monitors and reporting ambient air quality data (required under Sections 110 and 317 of the Act), developing state implementation plans (required under Section

*Since section 109 of the Clean Air Act requies that all NAAQS be reviewed every five years, it will be a repetitive one-time cost.

110), and enforcing these plans. For the most part, these are labor-intensive activities; hence, they are costly. The Economic Impact Assessment of the lead NAAQS (EPA, 1978b) provides data that can be used to roughly estimate the costs to state and local governments in implementing the promulgated CO NAAQS. That report suggests that these annual costs would be on the order of 50 person-years of effort plus $1.4 million in monitoring equipment and other capital costs. State/local control costs, then, would be around $6.9 million (in 1984 dollars) annually.

Total annual governmental CO control costs are derived simply by adding the annualized one-time standard-setting costs with other miscellaneous federal costs (assumed to be $0.4 million) and adding this sum to the $6.9 million state/local estimate. Total annual costs obtained in this manner for a five-year review cycle are approximately $7.7 million (in 1984 dollars).

2. Adjustment Costs for Unemployed Resources

Three types of costs occur if a regulatory action results in unemployment of labor or underuse of other productive resources. These are: loss of value in the resources required to produce lost output, resource reallocation costs (such as moving costs), and unemployment transfer payments. All three should be identified and costed out in a Regulatory Impact Analysis.

EPA does not believe any significant unemployment impacts are associated with the CO NAAQS. While there is no direct data on the point, there is indirect evidence for the conclusion contained in the economic analysis done on affected industries theoretically needing to install CO pollution control to meet alternative CO NAAQS. This analysis indicated that the economic impacts of doing so were small (EPA, 1985). Capital availability,

product price, and import substitution effects were minor; in addition, no plant closings were predicted due to the installation of CO controls.

3. Adverse Effects on Market Structure

As discussed earlier, the CO NAAQS has little impact on product price, capital availability, or import substitution. It also has marginal impact on increase in corporate debt or the debt/equity ratio (EPA, 1985). Thus, there will probably be little or no impact on market structure in the seven industrial categories affected by CO emission control needed to attain alternative CO NAAQS.

VI. EVALUATING BENEFITS AND COSTS

A. Introduction

Since it was felt that a credible attempt could not be made to estimate the benefits of various CO ambient standards within project constraints, and therefore a quantitative benefit-cost assessment could not be done, analyses of the incremental costs to reduce potentially adverse exposures to CO (hereafter referred to as ICAs) were performed instead. Costs associated with four alternative standards were analyzed along with changes in the number of sensitive people with COHb levels exceeding 2.1% and 2.5% and reductions in the total number of such exposures.

While this information does not reveal which standard would be preferred in an economic sense -- only the cost, and not the benefit, of reducing adverse exposures to CO has been estimated -- it does provide a partial measure of the relative impacts of the alternative CO standards.

B. Exposure and Cost Analyses

The incremental cost analysis relies on the results of the cost model discussed in Chapter V and the exposure analysis discussed in Chapter IV. The cost model uses a constrained least cost algorithm to determine the approximate order of imposition of control measures to achieve specific standards. This algorithm is considered reasonable for aggregated nationwide estimates, but it is not necessarily valid for specific nonattainment areas. Future control technologies are difficult to predict and, hence, the associated control costs cannot be estimated with precision. Also, human behavior patterns may change in ways that alter costs. For example, changes in the real cost of energy in the 1970's caused significant changes in the purchasing and driving habits of individuals in the U.S.

Consequently, predictions based on projected human behavior patterns should be viewed with caution.

The human exposure estimates are based on the exposure model described in Chapter IV. The exposure analysis was conducted in detail for four sample cities. To obtain nationwide estimates, the populations of other cities were assigned to one of the four cities based on geographic region, climate, peak CO concentrations, etc. Exposure estimates were extrapolated to the population assigned to each of the four cities. The sum of these values, adjusted for population growth and for other urban sites not accounted for in the city assignment, represent the nationwide estimates in 1987.* There is considerable uncertainty in these nationwide exposure estimates because (1) there is limited data available on a number of inputs required for the exposure analysis and (2) the estimates are extrapolated from only four cities.

In addition, the results of the cost and exposure analyses used in the incremental cost analysis are not derived in a consistent manner because they were originally conducted for different purposes with different underlying assumptions. These inconsistencies may bias the results when the analyses are used together.

The first such concern is with the estimated ambient CO concentrations that are the base case levels from which projected changes are calculated. Although the estimated concentrations chosen are appropriate for the purposes and requirements of each individual analysis, they are different.

The estimated concentrations for the cost analysis were derived from a review of ambient air quality data (EPA's SAROAD data base). Because

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*The exposure analysis 1987 results were extrapolated to 1995 by applying population growth rates.

the allowable exceedances are expected to be calculated as averages over three years, the fourth highest occurrence in the three year data set for each urbanized area was selected as the base case ambient CO concentrations for the one expected exceedances form of the standard. The second-highest daily maximum 8-hour average in a year was used for the 2nd-high (deterministic) form of the standard.

The exposure analysis used air quality indicators derived from a data base of ambient CO concentrations from monitoring stations for each hour throughout a given year. The year chosen depended upon the completeness of data. The stations were chosen as most representative of the different types of urban neighborhoods used in the exposure model. To estimate exposures when an area was just in compliance with a given alternative NAAQS, the exposure model proportionally adjusted the CO concentrations observed at each of the selected monitors so that the adjusted air quality indicator for the monitor with the highest CO concentrations would be just in compliance with the given NAAQS. The direction of bias resulting from the use of these different approaches is unclear.

A second area of concern is the different use of assumptions regarding attainment of the standards. The exposure analysis assumes that the highest monitor in each urban area will just attain the standard. The monitor station with the highest baseline reading is brought into compliance and the others in the area are adjusted in proportion to the change at the worst station. The cost analysis, however, is based on projections of baseline emissions given the nationwide FMVCP. The expected reductions in tailpipe emissions will result in some areas having ambient CO concentrations below those required by the standard. When full attainment cannot be reached, cost estimates will be low relative to the exposure estimates since the

exposure analysis assumes attainment. Consequently, the ICA results will be biased downward.

C. Incremental Cost Analysis

The results of the incremental cost analysis (ICA) are presented in Table 8 for increasing levels of control. Cost and exposure information from which the ICA results were derived are shown in Table 9. The ICA was performed for 1995 instead of 1987 because fewer residual non-attainment areas were obtained and comparisons should be made at full attainment. However, since full attainment was not obtained in 1995, there are inconsistencies between the exposure and cost analyses. In those areas that do attain, increased stringency in the standard will result in reduced exposures to potentially harmful COHb levels over what would otherwise occur.

Based on its reassessment of scientific evidence discussed previously in this RIA, EPA concludes that adverse health effects clearly occur, even in healthy individuals, at COHb levels in the range of 5 to 20 percent. EPA also remains concerned that adverse health effects may be experienced by large numbers of sensitive individuals with COHb levels in the range 3.0 to 5.0 percent. On this point, the CASAC similarly concluded after reviewing the scientific literature (not including the Aronow studies), "that the critical effects level for NAAQS-setting purposes is approximately 3 percent COHb (no including a margin of safety)" (Lippmann, 1984). In addition to concurring with EPA that cardiovascular effects are likely to occur at approximately 3 percent COHb, the CASAC also indicated that several studies (Drinkwater et al., 1974; Raven et al., 1974; and Davies and Smith, 1980) reporting physiological effects in the range 2.3-2.8 percent COHb lend support to concerns about low level CO exposures and should be considered

Table 8. Incremental Costs Per Exposure Reduction
1995

	Incremental Cost Per Exposure Reduction	
	Reductions in the Number of Cardiovasular Adults Exceeding 2.1% COHb ($/Person Reduction)	Reductions in the Number of Occurrences Among Cardiovascular Adults Exceeding 2.1% COHb ($/Exposure Reduction)
15/1 to 12/1	47-72	4-6
12/1 to 9/1	372-407	106-116
9/1 to 9/2	7,980-14,500	3,140-5,850

[a]All indicated standards are in expected exceedances except for 9/2 which is based on second high observations.

Table 9. Estimated Annualized Incremental Costs and Exposures for Increasing Levels of Control in 1995

Change in Standard[a]	Annual Incremental Cost[b] (10^6 1984 dollars)	Reduction in Estimated Annual Number of Cardiovascular Adults Exceeding 2.1% COHb[c,d]	Reduction in Estimated Annual Number of Occurrences Among Cardiovascular Adults Exceeding 2.1% COHb[c,e]	Reduction in Estimated Annual Number of Cardiovascular Adults Exceeding 2.5% COHb[c,d]	Reduction in Estimated Annual Number of Occurrences Among Cardiovascular Adults Exceeding 2.5% COHb[c,e]
15/1 to 12/1	30-46	633,000	7,420,000	494,000	1,910,000
12/1 to 9/1	175-192	472,000	1,660,000	44,400	81,300
9/1 to 9/2	40-74	5,000	12,700	0	0

[a]All indicated standards are in expected exceedances except for 9/2 which is based on second high observations.

[b]Computed from Table 7. Annual cost is the sum of annual operation and maintenance costs and annualized capital costs of pollution controls. An FMVCP of 3.4 gpm is assumed.

[c]Computed from Tables 4 and 5. Exposure numbers have been adjusted upward by 1.06 to reflect population growth between 1987 and 1995 based on 1980 OBERS BEA Regional Projections (DOC, 1981).

[d]Total number of individuals in the urban adult sensitive population who reach at least once COHb levels of 2.1% or more.

[e]Total number of occurrences of COHb episodes of 2.1% or more.

in determining whether a given standard provides an adequate margin of safety. As discussed previously, the Administrator has excluded Dr. Aronow's studies from consideration in his decision on the CO primary standards. Given the uncertainties regarding the lowest levels of COHb at which adverse health effects may occur, the results of the ICA, which used a 2.1% COHb cutpoint, should be viewed with caution.

D. Benefits Not Valued

Although the ambient CO standard focuses upon protecting the sensitive population from adverse health effects, benefits for other populations also may result from required pollution reductions. These benefits are not reflected in the ICA and bias the results in an upward manner. According to evidence evaluated in the Criteria Document (EPA, 1979b) and Addendum (EPA, 1984b), the general population may begin to experience central nervous system effects such as impaired vigilance, visual function, manual dexterity and ability to learn at COHb levels of 4-5%. This implies an increase in risks of accidents and reduced productivity or activity. Economic values on these vigilance and other unquantified effects (impaired fetal development, health effects for elderly individuals, etc.) are unknown, but they could add to the total benefits of lowered CO concentrations.

Other unquantified benefits accruing to the general population include certain option and existence values. The former result from uncertainties regarding the future demand for cleaner air. An example of such uncertainties would be not knowing whether an individual becomes part of the sensitive population. Existence values result from altruistic motivations by individuals to improve air quality even though they may never directly experience the change. An example might be an individual's willingness to pay to improve the air quality in the nation's major cities even though that person never visits major cities.

E. Findings and Conclusions

The chapter focused on estimation of the incremental costs associated with alternative CO NAAQS. The degree of uncertainty in making such estimates was identified by indicating limitations in the methodologies employed. Despite this uncertainty, deterministic estimates of incremental costs were developed for illustrative purposes.

ICA, in general, embodies the same methodology as cost effectiveness analysis (CEA). The usefulness of such tools can allow one to identify the least cost way to achieve a given goal. In addition, the methods can eliminate inefficient ways of achieving given goals. The techniques used above can in no way help identify the optimal goal in an economic efficiency sense. Hence, the ICA can only be used to identify the opportunity costs of implementing more stringent standards and cannot identify the socially desired CO NAAQS from an economic point of view.

VII. SUMMARY OF THE RATIONALE FOR SELECTING THE FINAL CARBON MONOXIDE STANDARDS

This chapter summarizes the Agency's rationale for selection of the final CO ambient standards. A more complete discussion of the rationale is contained in the Federal Register preamble for the final rule.

The Staff Reassessment (EPA, 1984a) and 1984 CASAC findings and recommendations (Lippmann, 1984) set forth a framework for considering whether revision of the primary CO standards is appropriate at this time. The discussion that follows relies heavily on that framework and on applicable supporting material in the Criteria Document (EPA, 1979b), Addendum (EPA, 1984b), Staff Paper (EPA, 1979a), and earlier CASAC closure letters (Hovey, 1979; Friedlander, 1982).

Based on its assessment of scientific evidence discussed in the Criteria Document and Addendum, EPA concludes that adverse health effects clearly occur, even in healthy individuals, at COHb levels in the range of 5 to 20 percent. EPA also remains concerned that adverse health effects may be experienced by large numbers of sensitive individuals with COHb levels in the range 3.0 to 5.0 percent. On this point, the CASAC similarly concluded after reviewing the scientific literature (not including the Aronow studies), "that the critical effects level for NAAQS-setting purposes is approximately 3 percent COHb (not including a margin of safety)" (Lippmann, 1984).

In addition to concurring with EPA that cardiovascular effects are likely to occur at approximately 3 percent COHb (Anderson et al., 1973), the CASAC also indicated that several studies (Drinkwater et al., 1974; Raven et al., 1974; and Davies and Smith, 1980) reporting physiological effects in

the range 2.3-2.8 percent COHb lend support to concerns about low level CO exposures and should be considered in determining whether a given standard provides an adequate margin of safety. The Administrator has excluded Dr. Aronow's studies from consideration in his decision on the CO primary standards.

Based on the exposure analysis results summarized previously in Chapter IV (Tables 4 and 5), 8-hour single exceedance CO standards in the range 9 to 12 ppm are estimated to keep more than 99 percent of the non-smoking cardiovascular population below 3.0 percent COHb. Different standards within this range would, of course, provide different levels of protection. For example, the current 9 ppm, 8-hour average standard is estimated to keep more than 99.9 percent of the adult cardiovascular population below 2.1 percent COHb. A 12 ppm, 8-hour standard is estimated to keep more than 99 percent of the population below 2.5 percent COHb. The 2.5 percent COHb level is in the range where physiological effects of concern to EPA and CASAC have been reported.

In considering whether revision of the existing primary CO standards is appropriate at this time, the Administrator has considered uncertainties regarding the lowest levels of COHb at which adverse health effects may occur, as well as uncertainties about the levels of COHb likely to result from CO exposure at the levels associated with attainment of alternative standards. More specifically, the Administrator considered the following factors and sources of uncertainty, discussed in the Staff Reassessment (EPA, 1984a), in his decision:

1. Human susceptibility to health effects and the levels at which these effects occur vary considerably among individuals, and EPA cannot be certain that experimental evidence has accounted for the full range of susceptibility. In addition, for ethical reasons, clinical investigators have generally excluded from their studies individuals who may be especially sensitive to CO exposure, such as those with a history of myocardial infarction or multiple disease states (e.g., both angina and anemia). Another factor is that, once the Aronow et al. studies are excluded there are no human exposure studies investigating effects on individuals with angina at COHb levels below the 2.9 percent level reported by Anderson et al. (1973).

2. There is some animal study evidence indicating that there may be detrimental effects on fetal development (e.g., reduced birth weight, increased newborn mortality, and behavioral effects) associated with CO exposure. Similar types of effects have also been found in studies examining effects of maternal smoking on human fetuses. However, it is not possible at this time to sort out the confounding influence of other components of tobacco smoke in causing the effects observed in the human studies. While human exposure-response relationships for fetal effects remain to be determined, these findings denote a need for caution in evaluating the margin of safety provided by alternative CO standards.

3. Other groups that may be affected by ambient CO exposures but for which there is little or no experimental evidence include: anemic individuals (over 3 million individuals), persons with chronic respiratory diseases (about 14 million individuals), elderly individuals (over 24.7 million individuals over 65 years old), visitors to high altitude locations, and individuals on certain medications. The levels of COHb that might produce adverse effects for each of these groups is uncertain. However, elevated

COHb levels in even a small percentage of this very large potentially sensitive population would translate to a significant number of individuals. The large size of the potentially sensitive population, then, argues for standards providing a greater margin of safety.

4. There are several uncertainties regarding the uptake of CO, including those related to the accuracy of the Coburn equation, in assessing variations in the population due to differing physiological parameters and exposure to varying air quality patterns.

5. Several factors contribute to uncertainties about the exposure estimates of the expected number of individuals achieving various COHb levels upon attainment of alternative standards. These factors include: the paucity of information on several of the needed inputs, the fact that nationwide estimates were extrapolated from only four urbanized areas, and the use of two representative sets (one for men and one for women) of physiological parameters (e.g., blood volume) rather than distributions of physiological parameters in applying the Coburn model to derive COHb estimates in the exposure analysis. As indicated in the Staff Reassessment (pp. 18-21), some individuals with physiological parameters that maximize uptake of COHb, if exposed to certain patterns of air quality attaining a 12 ppm, 8-hour standard, would likely exceed 3.0 percent COHb. Consequently, the Agency is concerned that a 12 ppm, 8-hour standard may not provide an adequate margin of safety. EPA is continuing its CO exposure research efforts, which should lead to future improvements in its exposure analysis and a better capability to assess the accuracy of the exposure estimates (Johnson, 1984; Hartwell et al., 1984).

6. There is uncertainty regarding adverse health effects that may result from very short duration, high-level CO exposures (the bolus effect).

As discussed in the proposal notice (45 FR 55077), existing air quality data indicate that attainment of a 9 ppm, 8-hour averaging time standard should limit the magnitude of short-term peak concentrations.

7. There is some concern about possible interactions between CO and other pollutants, although there is little experimental evidence to document such interactions at this time.

8. Given the unsettled nature of the scientific information bearing on the level of the standard, EPA believes that there is much to be said for a policy that would maintain the status quo until the data become more adequate. That is particularly so given the absence of the information indicating with some assurance that the present standard is set at an incorrect level. For the reasons stated in the preamble, the available information falls short of supporting such a finding.

While the CASAC concurred that the ranges of 9 to 12 ppm for the 8-hour and 25 to 35 ppm for the 1-hour primary standards recommended in the Staff Reassessment are scientifically defensible, they recommended that the Administrator consider choosing standards that maintain approximately the same level of protection as that afforded by the current standards (Lippman, 1984). In making its recommendation the CASAC cited the uncertainties associated with the scientific data base, margin of safety concerns, and its belief "... that where the scientific data, as in this case are subject to large uncertainties, it is desirable for the Administrator to consider a greater margin of safety than the numerical values of COHb generated by the Coburn equation might otherwise suggest" (Lippmann 1984).

Several ongoing human health effect studies are being conducted by EPA and other groups to investigate the effect of CO on aggravation of angina. Subjects in these studies are being exposed to CO levels that result in

blood COHb levels in the range 2.0 to 4.0 percent. One study is being conducted by EPA, several are being conducted at the request of EPA by the Health Effects Institute (HEI), and another study is being sponsored by the California Air Resources Board (CARB). The Health Effects Institute is an independent organization which sponsors research on automotive pollutants and is jointly funded by EPA and automobile manufacturers. The peer-reviewed results of the these studies are expected over the next 2 to 3 years. EPA will be initiating development of a new criteria document for CO in Fiscal Year 1986. Thus, the Agency should be in a good position to expeditiously assess the results from the above health studies, as well as other scientific evidence published since completion of the Addendum.

Given the uncertainty in the current data base and the fact that new studies are in progress, the Administrator considered deferring a final decision on the CO standards until these new studies have been completed. While this might allow the Administrator to base the decision on better information, the Clean Air Act appears to require periodic decisions on NAAQS notwithstanding any uncertainty in the data base. Deferring this decision would imply that the Agency has inadequate evidence to select an appropriate course of action at this time. However, both EPA and the CASAC have concluded that, even without the Aronow studies, a sufficient scientific data base exists upon which to base a decision. Given these findings, and the concern that a deferral of the decision could be perceived as a signal to relax or delay ongoing control programs, the Administrator has concluded that final action now on the CO standards is warranted and justified.

In reaching a final decision, the Administrator has focused primarily on the level of protection the CO standards should provide. As previously noted, after reassessing the available scientific data and EPA staff recommendations, the CASAC has recommended that the CO standards provide

protection approximately equal to the current standards. Based on EPA's assessment of the scientific data, the Administrator concurs with this recommendation. Retention of the current standards would, of course, satisfy this objective.

As discussed above, the standards proposed in August 1980 would also provide approximately the same level of protection as that afforded by the current standards. In addition, these standards would provide some technical changes that the Agency believes would be advantageous. However, the proposed changes would require some modification in the way attainment of the standards is determined. Given the uncertainties in the existing data base and the possibility that the results of the new studies in progress might warrant further revisions within a few years, the Administrator has concluded that it would not be prudent to promulgate the proposed revisions at this time, particularly when they would alter the manner in which attainment is determined.

In short, the Administrator has concluded that it would not be prudent to defer a decision on the CO standards pending the results of the new research mentioned above, that the standards should provide approximately the same level of protection as that afforded by the current standards, and that disruption of ongoing control programs should be minimized. Given these considerations, the Administrator has concluded that the best course of action is not to revise the CO primary standards at this time. Together with the Administrator's decision to rescind the secondary standards (discussed below), this decision completes the current review of the NAAQS for CO under section 109(d). The ongoing studies conducted by the Agency, by the HEI, and by the CARB (all discussed above) will, of course, be considered in the next 5-year review of the CO criteria and standards. Upon completion of this series of studies, the Agency plans to review the results with the

CASAC and assess the need for any revisions in the primary standards. If revisions in the standards seem appropriate, the Agency will act expeditiously to revise the standards.

WELFARE EFFECTS AND THE SECONDARY STANDARDS

Carbon monoxide is a normal constituent of the plant environment. Plants can both metabolize and produce CO. This may explain the fact that relatively high levels of CO are necessary before damage occurs to vegetation. The lowest level for which significant effects on vegetation have been reported is 100 ppm for 3 to 35 days. The effect observed in this study was an inhibition of nitrogen fixation in legumes. Since CO concentrations of this magnitude are rarely if ever observed in the ambient air, it is very unlikely that any damage to vegetation will occur from CO air pollution. No other effects on welfare have been associated with CO exposures at or near ambient levels. Because no standards appear to be requisite to protect the public welfare from any known or anticipated adverse effects from ambient CO exposures, EPA is rescinding the existing secondary standards.

VIII. STATUTORY AUTHORITY

The statutory authority for the retention of the CO primary NAAQS and revocation of the CO secondary NAAQS is contained in the Clean Air Act. Two sections of the Act govern the establishment and revision of NAAQS. Section 108 (42 U.S.C. 7408) requires EPA to document the most recent scientific information (criteria) on the health and welfare effects of certain air pollutants. Section 109 provides authority for reviewing the criteria and, as appropriate, for establishing and revising primary (health based) and secondary (welfare based) NAAQS. A more complete discussion of the legal authority for this final regulation is contained in the Federal Register preamble and in Chapter II of this RIA.

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